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### CHARACTERISTICS AND SAMPLING EFFICIENCIES OF MICROST VIRTUAL IMPACTORS

Jana S. Kesavan

RESEARCH AND TECHNOLOGY DIRECTORATE

Deborah Schepers



**GEO-CENTERS**

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<b>14. ABSTRACT</b> The aerosol sampling efficiencies of two prototype MicroST virtual impactors (BigRB and LittleRB) were determined at the U.S. Army Edgewood Chemical Biological Center (ECBC). These virtual impactors are designed to be connected serially to be a two-stage aerosol concentrator. The BigRB was tested at a total air flowrate of 24.5-32.3 Lpm with a minor airflow of 2.5-3.2 Lpm. The LittleRB was tested at a total airflow of 3.2-4.9 Lpm with a minor airflow of 0.6-0.7 Lpm. Sampling efficiency tests were conducted with 0.5-, 1.0-, 2.1-, and 3.0- $\mu$ m fluorescent PSL microspheres, and 3.9- $\mu$ m fluorescent oleic acid particles. Previous studies show that the concentration efficiency curves of virtual impactors have an inverted "U" shape; however, this is not seen with the BigRB and LittleRB virtual impactors for the particle sizes tested. The concentration efficiency of BigRB is between 6.4 and 13.6% for particle sizes 0.5-3.9 $\mu$ m, and the concentration efficiency of LittleRB is decreasing from 85.8 to 69.4% for particle sizes 0.5-3.0 $\mu$ m.					
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## PREFACE

The work described in this report was authorized under Project No. 206023.84BPO, Non-Medical CB Defense. The work was started in June 2005 and completed in July 2005. The data are recorded in Laboratory Notebook No. 04-0060, pages 3-15.

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## CONTENTS

1.	INTRODUCTION .....	7
2.	EQUIPMENT AND FACILITIES .....	7
2.1	Chamber .....	7
2.2	MicroST Virtual Impactors .....	9
2.3	Sampler Characteristics .....	9
3.	TEST PROCEDURES AND ANALYSIS .....	10
3.1	Sampling Efficiency Measurements .....	10
3.2	PSL Microsphere Tests .....	10
3.3	Sodium Fluorescein Tagged Oleic Acid (Fluorescent Oleic Acid) Tests .....	10
3.4	Analysis .....	11
4.	RESULTS .....	12
5.	DISCUSSION .....	12
6.	CONCLUSIONS .....	13
	LITERATURE CITED .....	15

## FIGURES

1.	70-m <sup>3</sup> Aerosol Chamber at ECBC .....	8
2.	MicroST Virtual Impactors, LittleRB and BigRB .....	9
3.	Microscopic Picture of Fluorescent Oleic Acid Droplets .....	11
4.	Sampling Efficiency of BigRB and LittleRB Virtual Impactors .....	13

## TABLES

1.	Characteristics of the MicroST Virtual Impactors, LittleRB and BigRB .....	9
2.	Average Sampling Efficiency of LittleRB and BigRB Virtual Impactors .....	12

# CHARACTERISTICS AND SAMPLING EFFICIENCIES OF MICROST VIRTUAL IMPACTORS

## 1. INTRODUCTION

This technical note is one in a continuing series of short reports intended to document and preserve the record of data from characterizing aerosol samplers/concentrators. This report is not intended to be a comprehensive study or analysis. A technical note simply records a limited set of observations, offers some preliminary analysis, and, if appropriate, provides a record of the measured data to the group that provided the device. Results of more thorough studies may be found in technical reports.

Air samplers/concentrators and detectors are important in the war against terrorism and on the battlefield to detect the presence of chemical, biological, and nuclear aerosols. Samplers/concentrators and detection systems must be evaluated and their performance efficiencies determined so that suitable samplers and detectors can be used. Knowledge of equipment performance enhances the ability to protect soldiers, first responders, and the general public. An ideal aerosol concentrator should be small, portable, use minimal power, and have a high concentration efficiency.

The concentration efficiency is defined as the efficiency with which particles in air are concentrated by the device. In testing, the concentrated aerosol is passed through a filter to collect the particles and quantify them. The concentration efficiency is determined by comparing the sample collected by the virtual impactor-filter to reference samples collected by two stationary open-face air filters.

In this study, the characteristics and sampling efficiencies of two prototype MicroST (MicroST, Inc., Vancouver, WA) virtual impactors (BigRB and LittleRB) were determined. In addition, characteristics such as dimensions and air flowrate were measured.

## 2. EQUIPMENT AND FACILITIES

### 2.1 Chamber.

The tests were conducted in a 70-m<sup>3</sup> biosafety Level 1+ chamber (Figure 1) at the U.S. Army Edgewood Chemical Biological Center (ECBC). Chamber temperature and humidity were set and maintained easily and accurately by a computer. This computer also controlled the power receptacles inside the chamber.

HEPA filters were installed at the air inlet to filter the air entering the chamber to achieve very low particle concentrations in the chamber. Similarly, HEPA filters were installed at the exhaust port to filter particles leaving the chamber. The aerosol concentration in the chamber was reduced by exhausting chamber air through the HEPA filters, and by pumping HEPA-filtered air into the chamber. The maximum amount of airflow that the exhaust pump can

exhaust from the chamber is approximately 700 ft<sup>3</sup>/min (approximately  $2 \times 10^4$  L/min). A small re-circulation system removed air from the chamber, passed it through a HEPA filter, and delivered it back to the chamber. This system is useful when the aerosol concentration in the chamber needs to be reduced by a small amount.

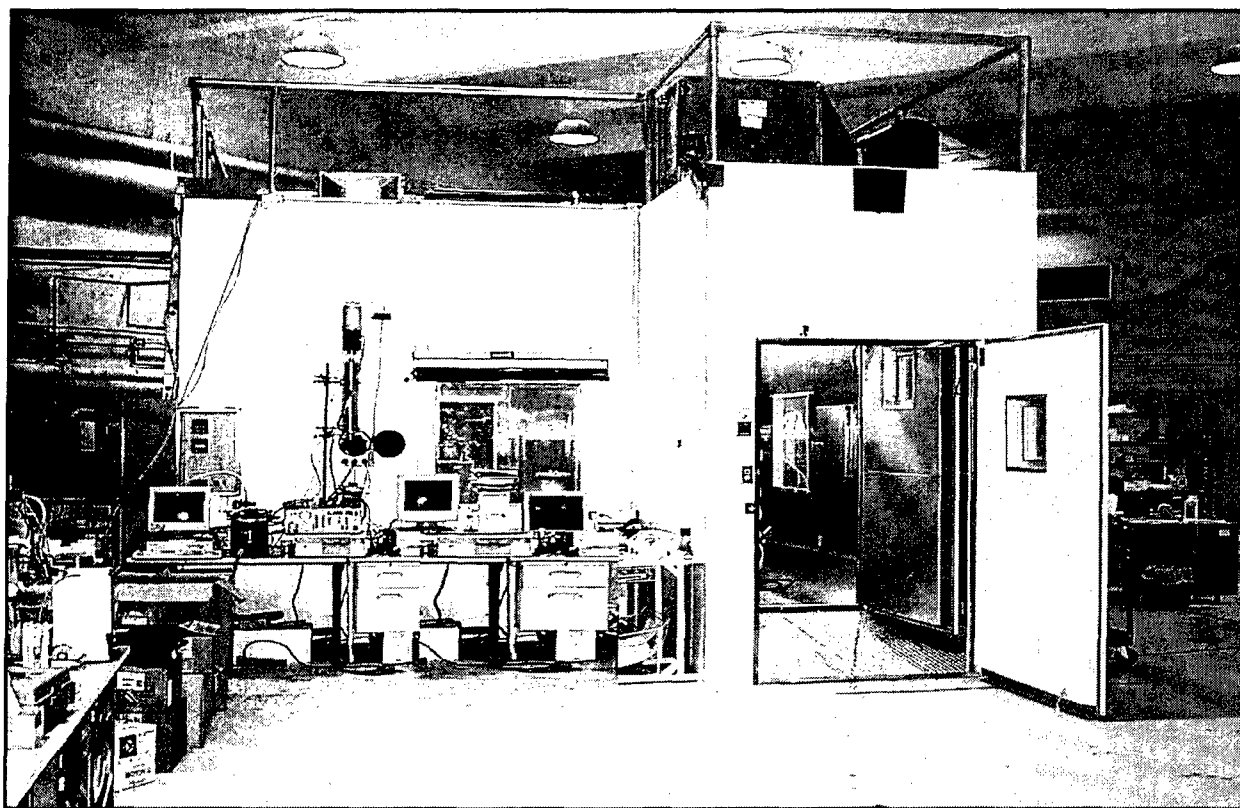


Figure 1. 70-m<sup>3</sup> Aerosol Chamber at ECBC

Aerosols can either be generated outside and then delivered to the chamber, or they can be generated inside the chamber. A fan mixes the chamber air before and/or during the experiment to achieve uniform aerosol concentration in the chamber. Previous tests show that mixing the aerosol in the chamber for 1 min is adequate to achieve uniform aerosol concentration.

For the PSL tests, to achieve more control of the aerosol concentration, tests were conducted in a 3-ft x 4-ft x 5-ft Plexiglass box that was placed in the 70-m<sup>3</sup> chamber. The samplers and reference filters were placed in the box; and the aerosol was delivered to the box. A fan in the box mixed the aerosol periodically to maintain uniform aerosol concentration.

## 2.2 MicroST Virtual Impactors.

Two prototype MicroST virtual impactors, BigRB and LittleRB, were characterized at ECBC (Figure 2). These virtual impactors are designed to be connected serially to be a two-stage aerosol concentrator. The BigRB was tested at a total air flowrate of 24.5-32.3 Lpm with a minor air flowrate of 2.5-3.2 Lpm. The LittleRB was tested at a total air flowrate of 3.2-4.9 Lpm with a minor air flowrate of 0.6-0.7 Lpm.

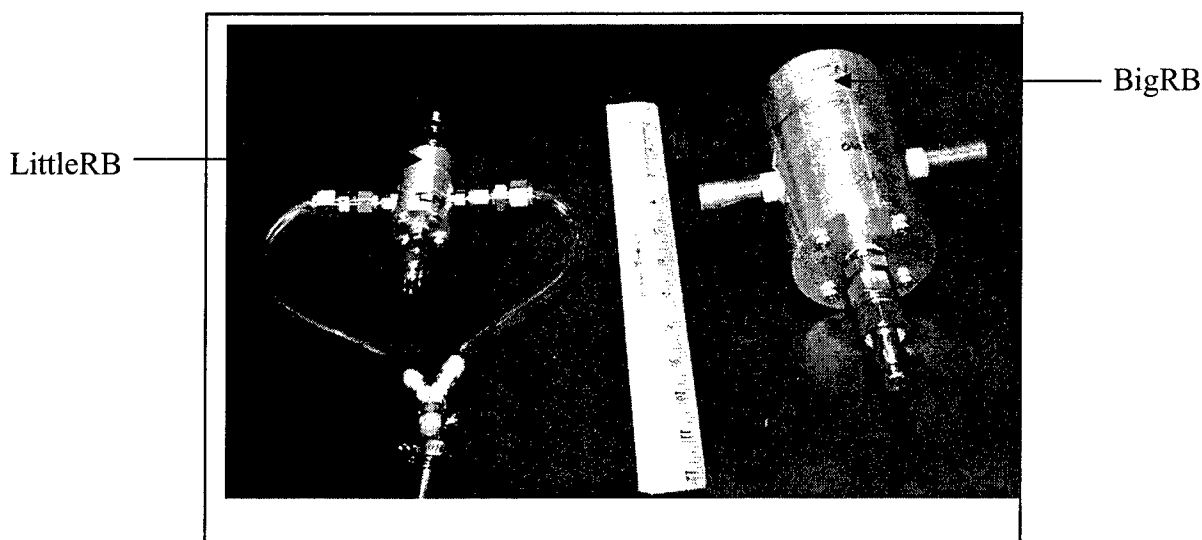


Figure 2. MicroST Virtual Impactors, LittleRB and BigRB

## 2.3 Sampler Characteristics.

Air flowrates of the reference filters and samplers were measured using a mass flow meter (4000 Series, TSI Inc., St. Paul, MN). The air flowrates, weight, and sampler dimensions are listed in Table 1.

Table 1. Characteristics of the MicroST Virtual Impactors, LittleRB and BigRB.

	LittleRB	BigRB
Air flowrate, Lpm		
Total	3.2-4.9	24.5-32.3
Major	2.6-4.2	22.0-28.2
Minor	0.6-0.7	2.5-3.2
Power	Lab pumps were used	Lab pumps were used
Weight (lb)	≈ 1	≈ 5
Dimensions (in.)	L = 2.5 D = 1.0	L = 6 D = 3

### 3. TEST PROCEDURES AND ANALYSIS

#### 3.1 Sampling Efficiency Measurements.

The sampling efficiency tests were conducted with two kinds of aerosols and corresponding analysis methods. The first method used monodisperse fluorescent polystyrene latex (PSL) microsphere. The second method used monodisperse fluorescent oleic acid particles. The concentrators and corresponding reference filters sampled the air simultaneously. The aerosol generation and analysis methods are described in detail in Sections 3.2 and 3.3.

#### 3.2 PSL Microsphere Tests.

Sampling efficiency tests were conducted with 0.5-, 1.0-, 2.1-, and 3.0-  $\mu\text{m}$  fluorescent PSL microspheres (Duke Scientific, Corp., Palo Alto, CA). The PSL aerosol was generated using a 24-jet Collison nebulizer, then passed through a radioactive isotope (Kr-85) neutralizer to reduce the charge on the particles. A 3-ft x 4-ft x 5-ft Plexiglass box was used in these tests to achieve more control of the aerosol concentration. The PSL aerosol was delivered into a Plexiglass box placed in the 70-m<sup>3</sup> chamber. The samplers and reference filters were placed in the Plexiglass box. The aerosol was generated for a short time and mixed before sampling. In addition, the air in the Plexiglass box was mixed periodically to achieve uniform concentration.

The samplers and corresponding reference filters sampled the PSL aerosol simultaneously for the same amount of time. Polycarbonate membrane filters (Osmonics Inc., Minnetonka, MN) were used as reference filters to collect the fluorescent PSL microspheres. After sampling, the samples were collected from the samplers and reference filters. Removing particles from membrane filters consisted of placing the membrane filters into 20 mL of filtered deionized water, hand shaking the mixture for 10 s, and then vortexing the mixture for 50 s. The hand shaking and vortexing were repeated four more times for a total of 5 min.

#### 3.3 Sodium Fluorescein Tagged Oleic Acid (Fluorescent Oleic Acid) Tests.

Sampling efficiency tests were also conducted with 3.9- $\mu\text{m}$  fluorescent oleic acid particles. The monodisperse fluorescent oleic acid particles were generated using a Vibrating Orifice Aerosol Generator (VOAG, TSI Inc., St. Paul, MN). As with the PSL tests, the generated aerosol was passed through a Kr-85 radioactive isotope neutralizer to reduce the charge on the particles, and then delivered to the chamber. Sampling the aerosol onto a microscope slide inserted into an impactor and then measuring the droplet size using a microscope determined the sizes of the fluorescent oleic acid particles. A microscopic picture of fluorescent oleic acid droplets on a slide is shown in Figure 3. The measured fluorescent oleic acid particle diameter was converted to an aerodynamic particle size using a spread factor (Olan-Figueroa et al., 1982)<sup>1</sup> and density. At the end of aerosol generation, the aerosol in the chamber was mixed for 1 min before sampling. The samplers and the corresponding reference filters sampled the aerosol simultaneously for the same amount of time. Glass fiber filters (Pall Corp., Ann Arbor, MI) were used as the reference filters to collect fluorescent oleic acid particles.

The glass fiber filters were removed from the filter holders, placed into a fluorescein recovery solution, and shaken on a table rotator (Lab-Line Instruments, Inc., Melrose Park, IL) for 1 hr. The recovery solution used in the tests contained water and alcohol with a pH between 8 and 10, obtained by adding a small amount of  $\text{NH}_4\text{OH}$  (e.g., 999 mL of water with 1 mL of 14.8 N  $\text{NH}_4\text{OH}$ ).

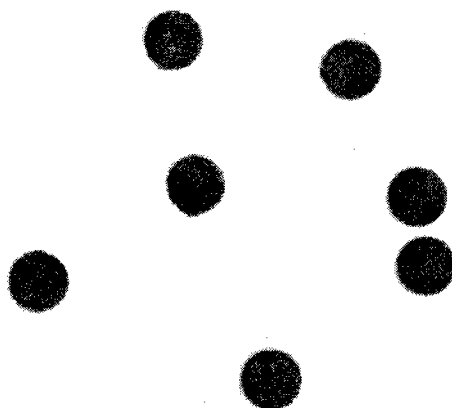


Figure 3. Microscopic Picture of Fluorescent Oleic Acid Droplets

Factors that affect fluorescein analysis and the removal of fluorescein from filters are described in detail by Kesavan et al. (2001).<sup>2</sup> The fluorescence of the solution was measured using a fluorometer. All the samples were analyzed either the same day as the experiment or the day after it.

#### 3.4 Analysis.

The sampling efficiency was determined by comparing the amount of fluorescent material collected by the concentrator-filter and the reference filters. The air flowrate of the sampler and reference filters, and the liquid volume of the samples and reference solutions were considered in the calculation.

The concentration efficiency was calculated using the following equation:

$$\text{Sampling Efficiency} = \frac{\left[ \frac{(\text{fluorometer reading of sampler}) \times (\text{liquid volume})}{(\text{air flow rate})} \right]}{\left[ \frac{(\text{fluorometer reading of reference filter}) \times (\text{liquid volume})}{(\text{air flow rate})} \right]} \times 100$$

#### 4. RESULTS

The sampler characteristics and sampling efficiency results are summarized in Tables 1 and 2. The sampling efficiency graphs for BigRB and LittleRB are shown in Figure 4.

Table 2. Average Sampling Efficiency of LittleRB and BigRB Virtual Impactors

Particle Size ( $\mu\text{m}$ )	Particle Type	Sampling Efficiency (%)	
		LittleRB	BigRB
0.5	PSL	$85.8 \pm 5.7$	$8.3 \pm 3.2^*$
1.0	PSL	$70.5 \pm 8.2$	$6.4 \pm 0.6$
2.1	PSL	$74.5 \pm 4.7$	$9.5 \pm 1.9$
3.0	PSL	$69.4 \pm 8.3$	$8.5 \pm 2.5$
3.9	Oil	$97.3 \pm 28.1^{**}$	$13.6 \pm 3.6$

\* mean  $\pm$  std

\*\* Based on flowrates measured before the test

#### 5. DISCUSSION

Two prototype MicroST virtual impactors (BigRB and LittleRB) were characterized at ECBC. The samplers were provided by MicroST, Inc. (Vancouver, WA) and were only available for 1 week of testing. Due to the limited time, the number of particle sizes and the number of tests were limited.

Previous studies have shown that the virtual impactor concentration efficiency curves have an inverted "U" shape; however, this is not seen with the BigRB and LittleRB virtual impactors for the particle sizes tested. The concentration efficiency of BigRB is between 6.4 and 13.6% for particle sizes from 0.5- to 3.9- $\mu\text{m}$ . The concentration efficiency of LittleRB is decreasing from 85.8 to 69.4% for particle sizes from 0.5 to 3.0  $\mu\text{m}$ .

The flowrates of the samplers were periodically measured, and the averages were used in the efficiency calculations. It was observed that the flow meter connector to the concentrator-filter was not fitting correctly, and this was corrected after the second flow measurements. Therefore, the measurements during the 3.9- $\mu\text{m}$  and pre 0.5- $\mu\text{m}$  measurements may not be accurate. The membrane filter flowrate measurements indicate that the flowrates of LittleRB went from 3.3 to 4.9 Lpm with the corrected fittings. Therefore, if the flowrate of 4.9 Lpm is used in place of the average flowrate for the 0.5- $\mu\text{m}$  tests, the efficiency results will decrease from  $85.8\% \pm 5.7$  to  $72.1\% \pm 4.8$ . Similarly, if we assume flow corrections will occur with the glass fiber filters for 3.9- $\mu\text{m}$  particles, then the efficiency results will decrease from  $97.3\% \pm 28.1$  to  $64.8\% \pm 18.7$ .

The flowrate of the Little RB was changed from 4.33 to 4.85 Lpm on run 5 of the 1- $\mu$ m test. The results indicate that there is no significant change in the sampling efficiency. Therefore, based on the flowrates, the results are not separated, and the average of all the runs was taken and reported herein.

Four to six tests were conducted with each particle size. If one efficiency result was significantly different from the others and was  $>100\%$ , then it was not included in the average calculations of the PSL tests. In the 3.9- $\mu$ m oleic acid tests, the efficiency results were  $>100\%$  in three runs, probably due to the use of a lower flowrate, as explained above in the previous paragraphs. These results were used in the average calculations because the flowrates were not re-measured with the glass fiber filters.

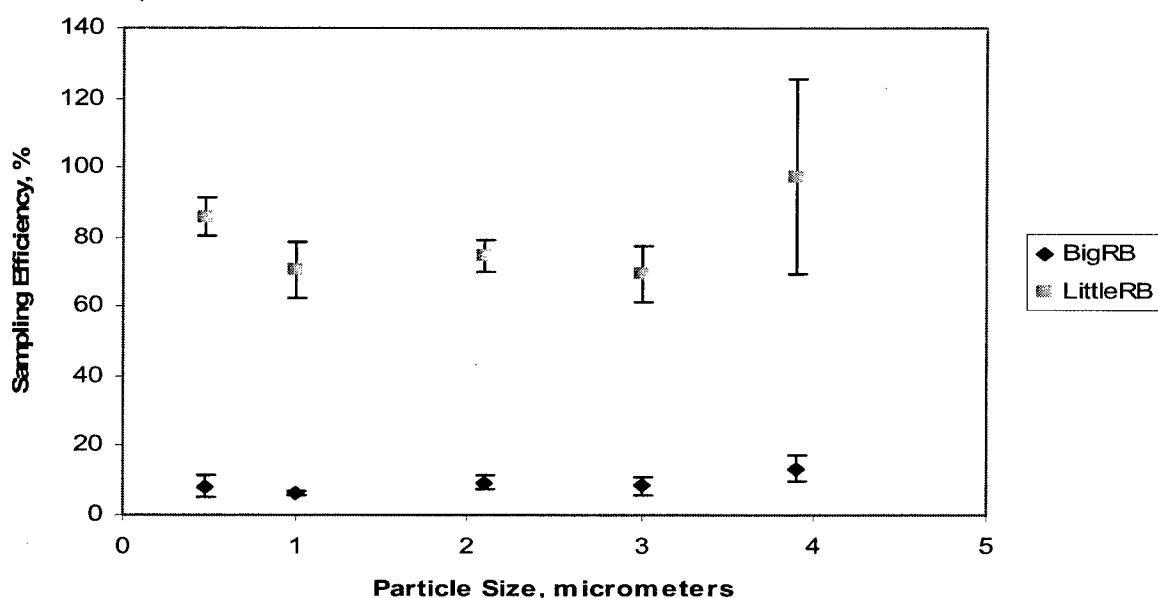


Figure 4. Sampling Efficiency of BigRB and LittleRB Virtual Impactors

## 6. CONCLUSIONS

Two prototype MicroST virtual impactors (BigRB and LittleRB) were characterized at the U.S. Army Edgewood Chemical Biological Center (ECBC) using 0.5-, 1.0-, 2.1-, and 3.0- $\mu$ m fluorescent PSL particles and 3.9- $\mu$ m fluorescent oleic acid particles. The BigRB had a total flowrate of 24.5-32.3 Lpm, and the LittleRB had a total flowrate of 3.2-4.9 Lpm. Both virtual impactors did not show the typical inverted "U" efficiency curves. The BigRB had a concentration efficiency of 6.4-13.6% for particle sizes tested, and the LittleRB had a concentration efficiency of 85.8-69.4% for 0.5- to 3- $\mu$ m particles.

Many samplers are characterized at ECBC, and the results are published in technical notes. When considering a sampler for an application, the decision should include information on sampling efficiency, concentration factor, sampler size, weight, airflow, pressure

drop (was not measured), and power consumption. Readers are advised that that these samplers may be modified and/or improved based on our tests, and may be improved as new technology becomes available. Therefore, a modified or improved sampler may have very different characteristics than given in this report.

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